Good Vibrations

Rhythms of the Brain
György Buzsáki
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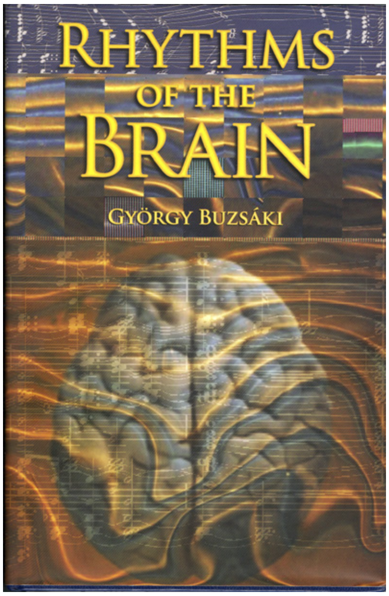

One Sunday afternoon in July 1924, an eccentric Austrian psychiatrist detected for the first time a faint electrical oscillation at about 10 Hz emanating from an awake intact human brain. Hans Berger carried out these experiments on his 15-year-old son in secret and only reported his discovery of the human encephalogram (EEG) 5 years later, disappointed that it had failed to provide the scientific basis for telepathy that he had long been seeking. Instead, the finding that the EEG changed with arousal states and adopted clearly abnormal patterns during seizures and other neurological disorders revolutionized the practice of neurology by providing the first objective and noninvasive tool to study the function, as opposed to the structure, of the human brain.

The subject of György Buzsáki's remarkable book, *Rhythms of the Brain*, is not so much the pathological synchronization of neurons during seizures but the many oscillations detected in the normal brain, mammalian and invertebrate, as it sleeps, wakes, and performs higher-level processes such as perception, attention, and memory. The author reminds the reader early on that every membrane, neuron, or circuit must have characteristic resonant properties. To an engineer, this is often a nuisance: excessive vibrations must be damped or cancelled for the machine to run smoothly, otherwise the periodic movements will cause excessive wear on the components. But what is one to do when faced with the background hum emanating from the normal brain? Is it just a by-product of neuronal and circuit computations, which must be kept in check to prevent run-away synchronization of larger and larger populations of neurons? Buzsáki elegantly and persuasively argues the opposite view throughout this book, that oscillations are the backbone upon which subsets of neurons are assembled and disassembled, as necessary substrates of attention, representation, and intention.

Of course, any book that approaches the most complex entity known to mankind with a theme apparently as simple as rhythms or oscillations can leave the reader wondering what it is really about. Buzsáki takes a highly original approach to cover the interface between cellular neuroscience and theories of brain function over a very broad range. He starts with some of the fundamental physics of oscillations and takes in some theoretical considerations of the behavior of distributed systems composed of connected nodes. He quickly covers much of the cellular neuroscience and anatomy of brain circuits relevant to the various rhythms detected in the brain and then moves on to the different brain states characterized by these rhythms. Finally, he turns his attention to the actual computations that these oscillations may well be subserving. The result is a highly original exposition of a broad swathe of modern neuroscience. Indeed, it brings together so many apparently disparate strands, and levels on the reductionistic scale, that it deserves a "must read" score, especially for neuroscientists looking to get an up-to-date and challenging exposition of many of the "big questions," even if they are not fundamentally interested in oscillations per se.

Two remarkably successful areas of endeavor within this field are given their due prominence. The proposal that oscillations in the gamma band (20–70 Hz) solve the "binding" problem has attracted much attention from Wolf Singer and others, initially in the field of sensory neuroscience but recently also in the motor system. The proposal, in a nutshell, is that different populations of neurons, each encoding a subset of a percept or motor task, can come together as a "gestalt" by oscillating in-phase within the gamma band. As Buzsáki points out, this potentially removes the need to postulate a hierarchy of neurons corresponding to higher and higher representations.

The roles of theta oscillations in spatial information processing and possibly in episodic memory formation are the subject of the last fifth of the book. This is a fast-moving field, and Buzsáki provides an excellent opportunity to catch up with some of the most fascinating developments in the temporal structure of spatial information processing. One of the most tantalizing recent observations is that the sequential firing of place cells can be preceded or followed by forward or reverse replay of the same sequences, compressed in time. Buzsáki summarizes the emerging knowledge on the "chronocircuitry" (to borrow a term from Peter Somogyi) that underlies the different rhythms of the hippocampal formation. And he does not shy from attempting a synthesis of results from his own laboratory and those of others to resolve some controversies regarding the dual role of the hippocampus in acting as a spatial map and as a memory-forming machine. This part may be beyond the reach of some readers, but because it is left until quite late, it should not discourage the more casual reader from appreciating the scenery on the way up.

Throughout most of the book, Buzsáki strikes an admirable balance of enthusiasm and caution in describing the possible ways that brain oscillations can contribute to computations. At times, however, I found myself on the sceptical side of the fence: Buzsáki holds up as highly significant the finding that the EEG spectrum shows a roughly inverse relationship between amplitude and frequency, such that there is a linear negative slope relating log(power) to log(frequency). A possible trivial explanation is that recruitment of many neurons into some coherent pattern of firing (giving a large amplitude signal) takes a relatively long time, while smaller populations can come in and out of phase-locking over shorter timescales. Nevertheless, I am generally suspicious of any correlation that needs a log-log plot for a linear relationship to emerge, and the fact that a similar amplitude $\propto 1/f$ relationship applies to almost all forms of music leaves me cold: it also applies when music is played backward, and that is not usually a particularly pleasant experience.

Ultimately, of course, the central hypothesis of the book, that population oscillations are necessary for the brain's useful computations, is quasi-untestable with current technology: one would have to preserve the ability of individual neurons to integrate and transmit information, while preventing their population synchronization. Nevertheless, the book makes a remarkably compelling argument in favor of temporal entrainment as necessary for large-scale computations, mainly because it is so difficult to conceive of alternative solutions to explain the enormous flexibility of the mammalian brain to assimilate salient signals, to ignore internal and external distractors, and possibly even to provide the appearance of unity to intentionality.

Although it is targeted at a broad audience, the exposition is far from condescending. A welcome concession to the reader who prefers to dip into the book is the wealth of entertaining and erudite digressions, many of which are included in footnotes. However, a full appreciation of the arguments is likely to require the reader's brain to exhibit relatively more gamma band oscillations and fewer delta and other slow rhythms than predicted by the general amplitude $\propto 1/f$ relationship. Nevertheless, if sharp wave ripples, associated with consummatory behavior in rodents, have the same connotations in humans, they too will likely occur in the reader's brain as a reward for the attention this book deserves.

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